Art. I.—*The Origin of the Volcanic Tuff of Pejark Marsh Victoria.*

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In view of the discovery of a native implement associated with fragments of bones of extinct marsupials under volcanic tuff at Pejark Marsh, near Terang, by Mr. A. J. Merry,[1] increased interest is attached to the task of ascertaining the probable age and origin of the tuff.

For this reason the opportunity was taken, while supervising some excavations being made at the Marsh, in 1909, in search of further evidence of man's antiquity, of paying a few hurried visits to various places in the neighbourhood likely to bear upon the subject. The following notes are principally the result of information so gained, but, as the time devoted to field investigation was unavoidably very limited, they must of necessity be brief, and perhaps omit some matter of value in deciding the issue in question.

An account of the excavations referred to, and of the occurrence of the tuff has already appeared.[2] It might be mentioned here, however, that the tuff is seen as a fine-grained bedded deposit, from 15 to 24 inches thick, along a drain made to carry the water away from the Pejark Marsh. The tuff has been laid down in an old swamp, now represented by a stiff, black clay bed, and abundant leaf impressions are present in the lower layers of the tuff. Resting on the tuff again, comes the heavy, black soil of the present marsh, some two or three feet in thickness.

The tuff is locally known as "sandstone," and is also called "sandstone tuff," on the quarter sheet No. 8 N.E. (New Series), of the Geological Survey of Victoria.

Previous reference to the deposit has been made by Professor J. W. Gregory,[3] when he states: "The broad down-shaped hill to the south-west of Camperdown, and the plains between Terang and Noorat, are formed of re-deposited, bedded tuffs. The low cliffs

1. An account of this discovery has not yet been published. The implement is in the possession of the National Museum, Melbourne.
2. Spencer and Walcott, "The Origin of Cuts on Bones of Australian Extinct Marsupials." Proc. Roy. Soc. Vict., pt. I., 1911, pp. 92-123.
3. The Geography of Victoria, Melb., 1903, p. 192, and revised edition, 1912, p. 204.

around Lake Terang, and a bank on the road leading to Gnotuk Park, near Camperdown, show the bedding, which indicates that the materials were laid down under water." If Professor Gregory's assertion be correct, that the tuff of the plains between Terang and Noorat, where the Pejark Marsh is situated, has been re-deposited, then the underlying clay bed may be younger, and not older than the volcanic rocks of the neighbourhood. This is a point of very considerable moment concerning the age of the human relic found in the clay bed, under the tuff.

In regard to the bedding of volcanic tuff, a common enough character in South-East Australia, Dr. T. S. Hall,[4] and Messrs. Mahony and Grayson[5] have shown, that it is by no means proof that the tuffs were laid down under water. On the contrary, the evidence indicates that they were mostly laid down on dry land, the exceptions being in those cases, such as at Pejark, where they may have been deposited in swamps or shallow lagoons.[6]

The direct deposition in these shallow and stagnant waters does not in any way affect the age of the tuffs; that question only arises where there is good and sufficient reason to believe that the tuffs have been, by the natural agency of wind or water, removed from their original places of deposition to others at a perhaps much later period.

The few facts gathered with regard to the Pejark tuff certainly seems to negative the idea that there has been any re-disposition of the material, and one of them is found in the numerous cavities it contains; a somewhat unusual feature in a rock of its character.

These cavities are of varying size and form, some being extremely regular, more especially the smaller ones, which are also generally spherical, but others again most irregular in shape. An examination in situ shows that the cavities are not all due to one cause. Some, the larger and mostly irregular ones, have a brownish coloured lining, and are found only near the bottom of the bed with the leaf impressions. These are undoubtedly the

4. Proc. Roy. Soc. Vict. Vol. XX., pt. I., 1909, pp. 20, 21.
5. Mem. Geol. Surv. of Vict., No. 9, 1910, p. 13, Geology of the Camperdown and Mt. Elephant Districts.
6. A specimen of tuff from Pejark Marsh, examined by F. Chapman, is stated by him to "show carbonized and iron-stained impressions of vegetable stems. When wax squeezes of these were taken they were seen to be triangular in section, and under the microscope show a structure exactly matching that of the surface in the living Victorian Marsh-loving *Cyperus lucidus*. The tuff specimen referred to also show excellent cross bedding disposed at a high angle to the plant-stems, thus indicating the formation of this deposit from gentle showers of volcanic dust."

result of the decay, and removal of vegetable remains. Higher up in the bed, where there is no sign of those remains, the smaller and more regular cavities occur in horizontal zones, and these likely enough have arisen through air entangled in the showers of ashes being carried with them to the bottom of the swamp, and there unable to escape.

In neither kind of cavity is there the slightest indication that it was formed by the gases given off by the decomposition of vegetation in the swamp in which the ashes fell. The presence of cavities due to air or other gases entangled in the shower of ashes, if it be a correct interpretation of the phenomenon, in itself sets at rest any doubts about the tuff not being in its original site, because such cavities could not have been retained during a re-distribution either by wind or water.

Mahony and Grayson,[7] in describing the microscopic characters of the Hampden tuffs, mention that a deposit at Blind Creek, about which some uncertainty exists as to whether it has been re-deposited or not, is similar to the tuffs occuring elsewhere in their original position. The same may be said of the Pejark tuff, as its character does not seem to differ from that of the beds of fine texture undoubtedly in situ. The Pejark bed is also sharply defined from both the underlying and overlying deposits, and there has been no mingling with extraneous material in any part of it. There are, then, no features in connection with the occurrence which might be held to indicate that it was laid down under conditions inconsistent with primary deposition.

The facts as they are, point not only to a sudden change in the nature of the deposited material, but to great rapidity of deposition with slight intervals of rest, during which the fine sediment suspended in the water of the lagoon or swamp settled, forming thin, impalpable seams in the tuff.

The whole bed was no doubt laid down in a comparatively short time, then earlier conditions again prevailed, and the present alluvial soil was deposited.

Regarding the origin of the tuff in question, there are three possible sources within the immediate neighbourhood of the place where the excavations were made, viz., Mt. Noorat, three miles to the north, Lake Keilambete, about two miles to the west, and Lake Terang, one mile due south.

The first of these sources and the most distant from the position mentioned, while leaving no question of its crater origin, has not

7. Loc. supra cit., p. 19.

yet supplied evidence of a sufficiently definite nature to prove that the tuff emanated from it. Mahony and Grayson[8] say that tuff was proved in wells sunk through the basalt to the north of the Mount, and they verbaly informed the writer that there was also evidence of tuff underlying the lavas in other directions.

This merely introduces the possibility of Mount Noorat having contributed to the Pejark tuff, but one of the other suggested places of origin is accompanied by evidence quite sound enough to fix it as the main source.

Lakes Keilambete and Terang, although surrounded by accumulations of tuff, have not been generally accepted as the sites of old volcanic vents.

Mr. A. R. C. Selwyn[9] thought they were more probably accidental depressions due to other causes, and Professor J. W. Gregory[10] is confident that they, as well as Lakes Bullemerri and Gnotuk, are not crater lakes, but occupy basins formed by subsidences in bedded volcanic tuff, which were probably caused by the eruptions of neighbouring volcanoes.

Mahony and Grayson,[11] on the other hand, hold that all these lakes are directly due to volcanic explosions, and with this view the writer is in accord. Their paper is a most valuable one, not only on account of the interesting matter it contains, but also because it is the only systematic account of the geology of the district yet published. As these notes must necessarily be brief, and only of a general nature, reference should be made to that paper.

The part of Lake Keilambete visited by the writer, like nearly the whole of its banks, was hidden by a luxurious growth of grass, with the exception of some outcrops of soft, tertiary, fossiliferous limestone underlying the superficial tuffs.[12]

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8. Loc. supra cit., p. 6.
9. Intercolonial Exhibition Essays, Melb., 1866.
10. The Geography of Victoria, Melb., 1903, p. 130. Revised Ed., 1913, pp. 131-136.
11. Loc. supra cit., p. 13.
12. Mr. F. Chapman, Palæontologist to the National Museum, who was good enough to examine all the fossiliferous material collected, determined the Lake Keilambete forms from the limestone as follows:—
    Foramnifera.—*Truncatulina lobatula*, W. and J. sp. Also others indet.
    Polyzoa.—Indet.
    Echinidermata.—*Echinocyamus* (*Scutellina*) *patella*, Tate sp, Eupatagus (?) laubel, Duncan.
    Brachiopoda.—*Magellania insolita*, Tate sp., and *M.* (?) *pectoralis* Tate sp.
    Pelecypoda.—*Pecten yahliensis*, Tate.
    Pisces.—*Lamna apiculata*, Ag. sp.
    Mr. Chapman places the limestone bed in the Janjukian series.
    Oyster shells of fossilized appearance occur on the beach of the lake, and it may be useful to record the fact here given to the writer by Mr. H. Quiney, of Mortlake, that many years ago an attempt was made to acclimatize oysters in the lake, but without success. It is to this source that the presence of the shells may be attributed.

The lake has an area of two square miles,[13] and is situated about two and a-half miles north-west of the township of Terang. Its circular form and low banks of volcanic tuff gently sloping into the surrounding plains on all sides, are very suggestive of volcanic origin. The fact that the banks are raised at all, unless they are of aeolian origin, makes it difficult to understand how they could have been formed if the lake is occupying a depression resulting from the withdrawal of material from below through the activity of neighbouring volcanoes.

It seems more reasonable to expect a gradual slope towards the lake by a sagging of the strata, instead of the reverse. Again, the symmetrical shape, which has been assumed, in place of one more or less irregular, as in the case of lakes situated in areas where the evidence supports an origin by subsidence, is more consistent with a volcanic origin. There is no evidence that this lake basin was formed in a depression in volcanic tuff. The tuff appears to have been deposited on a comparatively level land surface, through which the volcanic forces burst an opening. Mahony and Grayson[14] point out with regard to Lake Bullenmerri, which has only an area of a little over two square miles, is bounded by steep sides, and has its floor lying 700 feet below the highest part of the rim, that the formation of such a basin by the sinking of its floor has never been actually observed, but that there are instances of the production of similar depressions by paroxysmal explosions.

If it can be proved that the accumulations of tuff round the lake in situ thinned out as they receded from the lake itself, a strong piece of evidence would be established in favour of the basin being an explosion vent.

With regard to this, and several other points, Mr. A. J. Merry very kindly went to considerable trouble to ascertain what data were known from well sinkings in the neighbourhood. The result of his inquiries went to show that the well sinkings near Lake Keilambete all indicated a gradual reduction in the thickness of the tuff away from the lake, thus supplying the important evidence required. It is not certain, however, if this tuff extends to, and is continuous with, the Pejark bed. On the geological quarter sheet, buckshot gravel is seen to be the superficial deposit intervening between the former and the Pejark Marsh, and the nature of the underlying beds is not disclosed.

13. Intercolonial Exhibition Essays, Melbourne, 1866.
14. Loc. supra cit., p. 13.

While there may be certain characteristics absent from the formation of Lake Keilambete, they do not put nearly such a barrier in the way of ascribing its origin wholly, or in part to a volcanic explosion, as the presence of other characteristics do to the acceptance of the explanation that the lake basin is a simple subsidence in the land surface.

The site of Lake Keilambete may, therefore, be considered on good grounds the source from which the tuffs surounding it were derived, but evidence has not yet been collected to show that it has contributed to the Pejark Marsh tuff, although quite likely enough it has done so to some extent. Lake Terang has an area of one square mile,[15] or half that of Lake Keilambete, and, strangely enough, although it is without an apparent outlet, the water in it is fresh, unlike that of Keilambete. It also lacks the conspicuous circular form of Keilambete, and its irregularity, which is really not by any means marked, is emphasised by the varying height of the surrounding hills. The township of Terang is situated along the northern slope of these hills, but also spreads on to the level country, both eastward and northward. At the east end of the lake the hills are low, forming a gradual rise from the country beyond. Following along the township the elevation increases right to the west end of the lake, where the greatest prominence is attained, and is deemed worthy of the title of Mount Terang. From Mt. Terang, tapering hills extend further to the westward. Continuing round the lake the land rapidly falls away until a gap, forming the lowest part of the ring, is reached, and this is succeeded again on the south by somewhat prominent hills extending to another gap at the east end.

The greatest depth of water, which is in the centre of the lake, at the time of the Author's visit (1909) was said to be three feet. In this respect it differs much from Lake Keilambete, which, according to the geological quarter sheet, had a depth of 96 feet in the year 1888. It is also said that when the early settlers came to Terang there were 30 feet or more of water in Lake Terang, and that it even flowed out through the gap on the south-west side. As the surface of the water has not been lowered to this extent, it is believed by local residents that the bottom has risen.

The growth of peaty vegetation has given some foundation for this belief, but it does not explain the reduction in the volume of water. This can only be accounted for by its draining away along

15. Intercolonial Exhibition Essays, Melbourne, 1866.

some subterranean passage. As already mentioned the water is fresh, and it would require a considerable access to bring the level up to the gap, which is said to have been reached in the past. There is no doubt that there has been a large diminution in the quantity of water in the lake within recent years, and if this is caused by the supply, either superficial, or superficial and subterranean combined, as the case may be, being exceeded by the loss due to evaporation, it would be noticed in the salinity of the water. Keilambete has also been lowered in level to some extent during the same time, but the saltness of its waters is very marked.

A suggestion might here be made with regard to this difference in the water of the two lakes which in other respects seem to have much in common. It has been mentioned that in another paper[16] that at Pejark Marsh, in driving a crowbar through the yellow clay, on the top of which cut fragments of bone were found, the bar entered a softer stratum, and water flowed freely from the hole so made, showing that probably the water-bearing bed from which the local residents obtain their supplies, had been tapped. It is also thought that this might be the porous fossiliferous limestone of Tertiary age exposed along the shores of Lake Keilambete for some feet above the present water level.

On the shores of this lake wells have been sunk for some twenty or thirty feet in the limestone, it is said, and fresh water obtained, although the lake water itself is so saline from the absence of an outlet that it is unfit for consumption by stock. It, therefore, seems evident that the limestone bed is a channel by which the supply of water to Keilambete is augmented to some extent. Now at Lake Terang conditions are apparently different, and the process is reversed. In this case the water is either being forced out through the porous stratum into the surrounding country, where numerous wells are drawing it away more rapidly than before the stratum was tapped, and more rapidly than it can be naturally replenished, or else underground supplies, which were sufficient to balance the loss by subterranean outlets, have been intercepted. Mahony and Grayson[17] mention this as a probable factor in the desiccation going on at Lake Terang.

The sides of the lake, or ring of hills enclosing it, are composed principally of bedded tuffs. An extremely good exposure occurs

16. Spencer and Walcott, "The Origin of Cuts on Bones of Australian Extinct Marsupials." Proc. Roy. Soc. Vict., Pt. I., 1911, p. 93.
17. Loc. supra cit., p. 10.

just at the back of the Mechanics' Institute, where they have been quarried for building stone, and a clean vertical face about ten feet in height has been left. The beds here are of much coarser texture than at Pejark Marsh, and scattered through them are small lumps of white, indurated clay, which impart the effect produced by splashes of whitewash. An interesting feature was noticed here near the top of the beds, giving evidence that a volcanic vent was not far distant. This was the characteristic bend in the bedding of the tuff caused by impact of a falling body, and occurred under a cavity at one time occupied by a bomb or ejected block.

At Mt. Terang, where the tuff is being quarried just to the north of the summit, the beds are seen to be dipping, as far as can be made out, with the outward and northward slope of the hill. They are capped by a thin flow of scoriaceous basalt, which seems to form the cover of the hills extending to the west. Clay enclosures are also noticed here, but not so abundantly, and in one place the lava has intruded the tuff in the form of a small dyke now largely decomposed.

Just south of the summit of Mt. Terang, where a cutting for a road has been made, from what can be seen, the beds generally show a dip towards the lake, but as they have here been disturbed and become almost vertical within a short distance, where they abut on a coarse agglomerate or mass of volcanic ejectamenta, it is not quite certain whether this is the true direction of dip or not. It may be that this agglomerate is occupying a vent, and that the disturbance and rapid change in dip of the bedded tuffs has been caused by the downward drag of the volcanic material during its settlement. Enclosed in the agglomerate are lumps of flesh-coloured clay, reaching up to the size of a man's head. They are indurated by the heat to which they have been subjected, and mostly exhibit an imperfect prismatic structure from the same cause. These enclosures are of considerable interest on account of the fossils some of them contain, bearing witness of the presence of the marine tertiary beds underlying the volcanic deposits of the district, and from which they have been derived. Mr. F. Chapman identified these fossils as belonging to two Polyzoan genera—*Adeona* and *Lepralia*, and a brachiopod, doubtfully referred to the genus *Crania*. If then, we have here no evidence that the site of an old vent lies within the limits of Lake Terang, from whence came the various materials forming the mount and the surround-

ing hills? The ejected lumps of the older underlying rocks alone testify to the presence of a not distant source. On the eastward outward slope of the lake near the cemetery, a well put down passed through about 80 feet of tuff before striking water, but half a mile or so further east, poor "buckshot" country is encountered resting on, it is said, a clay bed. Again, near the summit of Mount Terang, another well was sunk, and a still greater thickness of tuff was met with. Mr. Merry also says that to the west and south of the lake the good volcanic country is succeeded by "buckshot" and clay lands. The geological quarter sheet shows what is called the "older volcanic series," giving place to "buckshot" gravel to the west, but to the north extending to the limits of the quarter sheet. The title given to this series is badly chosen, and misleading, as it does not refer to the older basalts, known as such since the time of the first geological survey of Victoria, but to a section of the newer volcanic rocks belonging to a much more recent period. Apart from the confusion occasioned thereby, "older" is an inappropriate term to employ, as the basalt it is applied to, is in part superficial, and at Lake Terang mapped right up to its side, so that it must be younger than the tuffs there, and Mahony and Grayson state that the basalts belong to one cycle of activity, no sharp line of demarcation separating them. These authors[18] have very properly in their paper substituted the terms "earlier" and "later" for the older and newer volcanic series of the quarter sheet. To the north of Lake Terang we know that at the Pejark drain, distant about a mile, there is at the most only two feet of tuff, and Mr. Merry ascertained that between the drain and the lake the tuff or "sandstone" had been encountered in every well sinking and cellar excavation, increasing in thickness as the lake was approached. The actual thickness of the tuff bed on that side of the lake could not be found out. The section behind the Mechanics' Institute shows a face of 10 feet. This establishes the continuity of the Pejark and Lake Terang tuffs, and makes it probable enough that they originated from the same point, although of course, as already stated, they may have blended to some extent to the west and north with the tuffs which emanated from the site of Lake Keilambete and from Mt. Noorat.

As the tuffs of Lake Terang are unquestionably occupying their original place of deposition, and are continuous with, and thin out into, the Pejark beds, there seems no reason to attribute the

18. Loc. supra cit., p. 4.

occurrence of the latter to re-deposition. If Lake Terang does not represent an ancient centre of volcanic activity, it is inconceivable how a mass of volcanic ashes and coarser ejectamenta, covered with lava for the greater part, and undoubtedly in situ, came to be piled up there where there is no evidence whatever to connect its presence with any other possible source of origin.

It is possible, however, that the crater basin ocupied by the lake may have been enlarged by subsidence through the withdrawal of material from below.

In view of the facts given it may fairly safely be taken that any works of man discovered beneath the tuffs of the areas under consideration would at least put his history back to the last great epoch of volcanic activity in south-west Victoria, and make him the contemporary of our giant extinct marsupial fauna.